

## 4.6: Neutralization Reactions

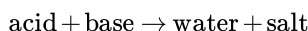
### Learning Objectives

- Identify an acid and a base.
- Identify a neutralization reaction and predict its products.

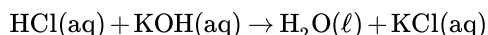
In Chapter 3, we defined an acid as an ionic compound that contains  $\text{H}^+$  as the cation. This is slightly incorrect, but until additional concepts were developed, a better definition needed to wait. Now we can redefine an acid: an **acid** is any compound that increases the amount of hydrogen ion ( $\text{H}^+$ ) in an aqueous solution. The chemical opposite of an acid is a base. The equivalent definition of a base is that a **base** is a compound that increases the amount of hydroxide ion ( $\text{OH}^-$ ) in an aqueous solution. These original definitions were proposed by Arrhenius (the same person who proposed ion dissociation) in 1884, so they are referred to as the **Arrhenius definition** of an acid and a base, respectively.

You may recognize that, based on the description of a hydrogen atom, an  $\text{H}^+$  ion is a hydrogen atom that has lost its lone electron; that is,  $\text{H}^+$  is simply a proton. Do we really have bare protons moving about in aqueous solution? No. What is more likely is that the  $\text{H}^+$  ion has attached itself to one (or more) water molecule(s). To represent this chemically, we define the **hydronium ion** as  $\text{H}_3\text{O}^+$ , which represents an additional proton attached to a water molecule. We use the hydronium ion as the more logical way that a hydrogen ion appears in an aqueous solution, although in many chemical reactions  $\text{H}^+$  and  $\text{H}_3\text{O}^+$  are treated equivalently.

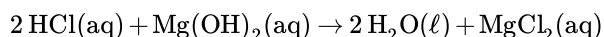
The reaction of an acid and a base is called a **neutralization reaction**. Although acids and bases have their own unique chemistries, the acid and base cancel each other's chemistry to produce a rather innocuous substance—water. In fact, the general reaction between an acid and a base is:



where the term **salt** is generally used to define any ionic compound (soluble or insoluble) that is formed from a reaction between an acid and a base. (In chemistry, the word *salt* refers to more than just table salt.) For example, the balanced chemical equation for the reaction between  $\text{HCl}(\text{aq})$  and  $\text{KOH}(\text{aq})$  is



where the salt is KCl. By counting the number of atoms of each element, we find that only one water molecule is formed as a product. However, in the reaction between  $\text{HCl}(\text{aq})$  and  $\text{Mg}(\text{OH})_2(\text{aq})$ , additional molecules of HCl and  $\text{H}_2\text{O}$  are required to balance the chemical equation:



Here, the salt is  $\text{MgCl}_2$ . (This is one of several reactions that take place when a type of antacid—a base—is used to treat stomach acid.)

### ✓ Example 4.6.1

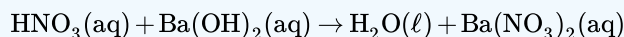
Write the neutralization reactions between each acid and base.

- $\text{HNO}_3(\text{aq})$  and  $\text{Ba}(\text{OH})_2(\text{aq})$
- $\text{H}_3\text{PO}_4(\text{aq})$  and  $\text{Ca}(\text{OH})_2(\text{aq})$

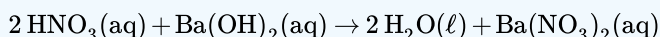
#### Solution

First, we will write the chemical equation with the formulas of the reactants and the expected products; then we will balance the equation.

- The expected products are water and barium nitrate, so the initial chemical reaction is

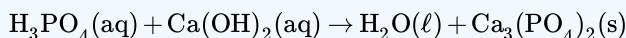


To balance the equation, we need to realize that there will be two  $\text{H}_2\text{O}$  molecules, so two  $\text{HNO}_3$  molecules are required:

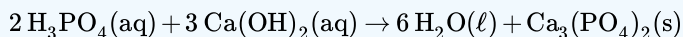


This chemical equation is now balanced.

b. The expected products are water and calcium phosphate, so the initial chemical equation is



According to the solubility rules,  $\text{Ca}_3(\text{PO}_4)_2$  is insoluble, so it has an (s) phase label. To balance this equation, we need two phosphate ions and three calcium ions. We end up with six water molecules to balance the equation:

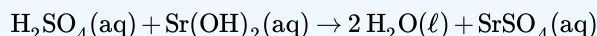


This chemical equation is now balanced.

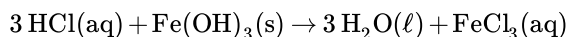
### ? Exercise 4.6.1

Write the neutralization reaction between  $\text{H}_2\text{SO}_4(\text{aq})$  and  $\text{Sr}(\text{OH})_2(\text{aq})$ .

**Answer**

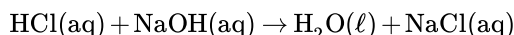


Neutralization reactions are one type of chemical reaction that proceeds even if one reactant is not in the aqueous phase. For example, the chemical reaction between  $\text{HCl}(\text{aq})$  and  $\text{Fe}(\text{OH})_3(\text{s})$  still proceeds according to the equation:

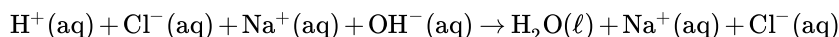


even though  $\text{Fe}(\text{OH})_3$  is not soluble. When one realizes that  $\text{Fe}(\text{OH})_3(\text{s})$  is a component of rust, this explains why some cleaning solutions for rust stains contain acids—the neutralization reaction produces products that are soluble and wash away. (Washing with acids like  $\text{HCl}$  is one way to remove rust and rust stains, but  $\text{HCl}$  must be used with caution!)

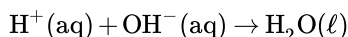
Complete and net ionic reactions for neutralization reactions will depend on whether the reactants and products are soluble, even if the acid and base react. For example, in the reaction of  $\text{HCl}(\text{aq})$  and  $\text{NaOH}(\text{aq})$ ,



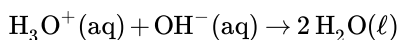
the complete ionic reaction is



The  $\text{Na}^+(\text{aq})$  and  $\text{Cl}^-(\text{aq})$  ions are spectator ions, so we can remove them to have

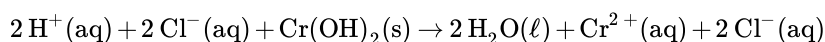


as the net ionic equation. If we wanted to write this in terms of the hydronium ion,  $\text{H}_3\text{O}^+(\text{aq})$ , we would write it as

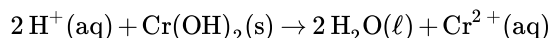


With the exception of the introduction of an extra water molecule, these two net ionic equations are equivalent.

However, for the reaction between  $\text{HCl}(\text{aq})$  and  $\text{Cr}(\text{OH})_2(\text{s})$ , because chromium(II) hydroxide is insoluble, we cannot separate it into ions for the complete ionic equation:



The chloride ions are the only spectator ions here, so the net ionic equation is

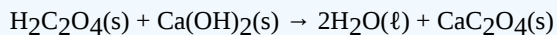


### ✓ Example 4.6.2

Oxalic acid,  $\text{H}_2\text{C}_2\text{O}_4(\text{s})$ , and  $\text{Ca}(\text{OH})_2(\text{s})$  react very slowly. What is the net ionic equation between these two substances if the salt formed is insoluble? (The anion in oxalic acid is the oxalate ion,  $\text{C}_2\text{O}_4^{2-}$ .)

**Solution**

The products of the neutralization reaction will be water and calcium oxalate:

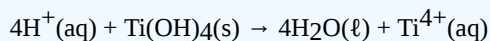


Because nothing is dissolved, there are no substances to separate into ions, so the net ionic equation is the equation of the three solids and one liquid.

### ? Exercise 4.6.2

What is the net ionic equation between  $\text{HNO}_3(\text{aq})$  and  $\text{Ti}(\text{OH})_4(\text{s})$ ?

#### **Answer**



### Key Takeaways

- The Arrhenius definition of an acid is a substance that increases the amount of  $\text{H}^+$  in an aqueous solution.
- The Arrhenius definition of a base is a substance that increases the amount of  $\text{OH}^-$  in an aqueous solution.
- Neutralization is the reaction of an acid and a base, which forms water and a salt.
- Net ionic equations for neutralization reactions may include solid acids, solid bases, solid salts, and water.

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